

**TRANSMISSIVE OPTICAL ELEMENTS INCLUDING TRANSPARENT  
PLASTIC SHELL HAVING A PHOSPHOR DISPERSED THEREIN, AND  
METHODS OF FABRICATING SAME**

**Field of the Invention**

This invention relates to light emitting devices and fabricating methods therefor, and more particularly to packaging and packaging methods for light emitting devices.

5

**Background of the Invention**

Semiconductor light emitting devices such as Light Emitting Diodes (LED) or laser diodes are widely used for many applications. As is well known to those having skill in the art, a semiconductor light emitting diode is generally packaged by at least partially surrounding the semiconductor light emitting diode with a dome-shaped transparent plastic shell.

10

It is often desirable to incorporate a phosphor into the light emitting device, to enhance the emitted radiation in a particular frequency band and/or to convert at least some of the radiation to another frequency band. Phosphors may be included in a light emitting device using many conventional techniques. In one technique, phosphor is coated inside and/or outside the plastic shell. In other techniques, phosphor is coated on the semiconductor light emitting device itself, for example using electrophoretic deposition. In still other embodiments, a drop of a material such as epoxy that contains phosphor therein may be placed inside the plastic shell, on the semiconductor light emitting device and/or between the device and the shell. LEDs that employ phosphor coatings are described, for example, in U.S. Patents, 6,252,254; 6,069,440; 5,858,278; 5,813,753; 5,277,840; and 5,959,316.

15

20

Packaging may constitute a major portion of the expense and/or fabrication time for a finished light emitting device.

25

### **Summary of the Invention**

Some embodiments of the present invention form a transmissive optical element by filling a mold with molten liquid that comprises a transparent plastic and a phosphor additive, and allowing the molten liquid to solidify to produce the transmissive optical element having phosphor dispersed therein. Accordingly, these embodiments need not provide a separate phosphor coating or phosphor-containing encapsulant, although they may.

In some embodiments of the present invention, the transmissive optical element is a dome through which a light emitting device emits light. In these embodiments, a transparent core may also be formed inside the dome. Alternatively, the transparent core may first be formed and then the molding may be performed by filling a domed-shaped mold that includes the transparent core with a molten liquid that comprises a transparent plastic and a phosphor additive.

In still other embodiments, the transmissive optical element is a keypad key through which a light emitting device emits light. In yet other embodiments, the optical element is a keypad key face through which a light emitting device emits light. In these embodiments, a separate step may be provided for forming a keypad key wall that is attached to the keypad key face.

Transmissive optical elements according to some embodiments of the present invention include a shell that comprises a transparent plastic including a phosphor dispersed therein. In some embodiments, the phosphor is uniformly dispersed in the shell, whereas in other embodiments, the phosphor is nonuniformly dispersed in the shell.

In some embodiments, the shell is a dome-shaped shell and the transmissive optical element further comprises a transparent inner core inside the dome-shaped shell. In some embodiments, the transparent inner core fills the dome-shaped shell to provide a hemispherical optical element. In yet other embodiments, the dome-shaped shell may be combined with a semiconductor light emitting device that is configured to emit light into and through the transparent inner core and through the dome-shaped shell, to emerge from the dome-shaped shell. Still other embodiments add a mounting substrate that is adjacent the semiconductor light emitting device and remote from the transparent inner core. Still other embodiments add an encapsulant between the light emitting device and the transparent core.

In other embodiments of the invention, the shell is a keypad key shell including a keypad key face and a keypad key wall that extends from the keypad key face. In some of these embodiments, phosphor is uniformly dispersed in the keypad key shell. In other embodiments, phosphor is uniformly dispersed in the keypad key face, and is not included in the keypad key wall. In still other embodiments, phosphor is nonuniformly dispersed in the keypad key face and may or may not be included in the keypad key wall.

Light emitting devices according to other embodiments of the present invention include a mounting substrate and a semiconductor light emitting device on the mounting substrate. A dome-shaped shell that comprises a transparent plastic including a phosphor dispersed therein is provided on the mounting substrate and at least partially surrounds the semiconductor light emitting device. A transparent inner core is provided inside the dome-shaped shell. In other embodiments, an encapsulant is provided between the semiconductor light emitting device and the transparent inner core. In still other embodiments, the mounting substrate includes therein a cavity, the semiconductor light emitting device is at least partially in the cavity, the dome-shaped shell is on the mounting substrate surrounding the cavity and the encapsulant is in the cavity.

#### **Brief Description of the Drawings**

Figures 1A-1H are cross-sectional views of transmissive optical elements according to first embodiments of the present invention that may provide semiconductor light emitting devices.

Figures 2A and 2B are cross-sectional views of semiconductor light emitting devices according to other embodiments of the present invention.

Figures 3A-3F are cross-sectional views of optical elements according to still other embodiments of the invention that may provide keypad keys.

Figure 4 is a schematic diagram of a molding apparatus that may be used to fabricate optical elements according to embodiments of the present invention.

Figures 5 and 6 are flowcharts of operations that may be performed to fabricate light emitting devices according to embodiments of the present invention.

### Detailed Description

The present invention now will be described more fully hereinafter with reference to the accompanying drawings, in which embodiments of the invention are shown. This invention may, however, be embodied in many different forms and should not be construed as limited to the embodiments set forth herein. Rather, these  
5      embodiments are provided so that this disclosure will be thorough and complete, and will fully convey the scope of the invention to those skilled in the art. In the drawings, the size and relative sizes of layers and regions may be exaggerated for clarity. Like numbers refer to like elements throughout.

10      It will be understood that when an element such as a layer, region or substrate is referred to as being "on" another element, it can be directly on the other element or intervening elements may also be present. It will be understood that if part of an element, such as a surface of a conductive line, is referred to as "outer," it is closer to the outside of the device than other parts of the element. Furthermore, relative terms  
15      such as "beneath" may be used herein to describe a relationship of one layer or region to another layer or region relative to a substrate or base layer as illustrated in the figures. It will be understood that these terms are intended to encompass different orientations of the device in addition to the orientation depicted in the figures. Finally, the term "directly" means that there are no intervening elements.

20      Figures 1A-1H are cross-sectional views of transmissive optical elements according to various embodiments of the present invention. These optical elements may be used to package light emitting devices, such as semiconductor light emitting devices.

As shown in Figure 1A, transmissive optical elements according to some  
25      embodiments of the present invention include a shell **100** that comprises transparent plastic. The shell **100** includes a phosphor **110** dispersed therein. As is well known to those having skill in the art, the shell may comprise polycarbonate material and/or other conventional plastic materials that are used to fabricate transmissive optical elements. Moreover, the phosphor can comprise any conventional phosphor including  
30      cerium-doped YAG and/or other conventional phosphors. In some specific embodiments, the phosphor comprises Cesium doped Yttrium Aluminum Garnet (YAG:Ce). In other embodiments, nano-phosphors may be used. Phosphors are well known to those having skill in the art and need not be described further herein.

In Figure 1A, the phosphor **110** is uniformly dispersed within the shell **100**. In contrast, in Figure 1B, the phosphor **120** is nonuniformly dispersed in the shell. Various patterns of phosphor **120** may be formed, for example, to provide areas of higher intensity and/or different color and/or to provide various indicia on the shell **100** when illuminated. In Figures 1A-1B, the shell **100** is a dome-shaped shell. As used herein, the terms "dome" and "dome-shaped" refer to structures having a generally arcuate surface profile, including regular hemispherical structures as well as other generally arcuate structures that do not form a regular hemisphere, which are eccentric in shape and/or have other features, structures and/or surfaces. Moreover, as will be described below, various other shapes may be provided.

Referring now to Figure 1C, one or more coatings **130** may be provided on the outside of the shell **100**. The coating may be a protective coating, a polarizing coating, a coating with indicia and/or any other conventional coating for an optical element that is well known to those having skill in the art. In Figure 1D, one or more inner coatings **140** is provided on the inner surface of the shell **100**. Again, any conventional coating or combination of coatings may be used.

Moreover, other embodiments of the invention provide both an inner and an outer coating for the shell **100** that includes uniformly distributed phosphor **110** and/or non-uniformly distributed phosphor **120** therein. By providing an inner and outer coating, improved index matching to the phosphor may be provided. Thus, three layers may be injection molded according to some embodiments of the present invention. Other embodiments of the present invention can use an index matching media, such as a liquid and/or solid gel, within the shell, to assist in index matching. The use of inner and outer layers can reduce the number of photons that can be trapped in the phosphor-containing layer due to index matching issues.

Figure 1E describes other embodiments of the present invention wherein a transparent inner core **150** is provided inside the dome-shaped shell **100**. In some embodiments, as also shown in Figure 1E, the transparent inner core **150** fills the dome-shaped shell **100**, to provide a hemispherical optical element. The transparent inner core **150** may be uniformly transparent and/or may include translucent and/or opaque regions therein. The transparent inner core **150** may comprise glass, plastic and/or other optical coupling media.

Figure 1F illustrates other embodiments of the present invention wherein a phosphor-containing shell **100** is combined with a semiconductor light emitting

device 160 that is configured to emit light 162 into and through the transparent inner core 150 and through the dome-shaped shell 100, to emerge from the dome-shaped shell 100. The semiconductor light emitting device can comprise a light emitting diode, laser diode and/or other device which may include one or more semiconductor layers, which may comprise silicon, silicon carbide, gallium nitride and/or other semiconductor materials, a substrate which may comprise sapphire, silicon, silicon carbide or other microelectronic substrates, and one or more contact layers which may comprise metal and/or other conductive layers. The design and fabrication of semiconductor light emitting devices are well known to those having skill in the art.

For example, the light emitting elements 160 may be gallium nitride based LEDs or lasers fabricated on a silicon carbide substrate such as those devices manufactured and sold by Cree, Inc. of Durham, North Carolina. For example, the present invention may be suitable for use with LEDs and/or lasers as described in United States Patent Nos. 6,201,262, 6,187,606, 6,120,600, 5,912,477, 5,739,554, 5,631,190, 5,604,135, 5,523,589, 5,416,342, 5,393,993, 5,338,944, 5,210,051, 5,027,168, 5,027,168, 4,966,862 and/or 4,918,497, the disclosures of which are incorporated herein by reference as if set forth fully herein. Other suitable LEDs and/or lasers are described in published U.S. Patent Publication No. US 2003/0006418 A1 entitled *Group III Nitride Based Light Emitting Diode Structures With a Quantum Well and Superlattice, Group III Nitride Based Quantum Well Structures and Group III Nitride Based Superlattice Structures*, published January 9, 2003, as well as published U.S. Patent Publication No. US 2002/0123164 A1 entitled *Light Emitting Diodes Including Modifications for Light Extraction and Manufacturing Methods Therefor*. Furthermore, phosphor coated LEDs, such as those described in United States Provisional Application Serial No. 60/411,980, entitled *Phosphor-Coated Light Emitting Diodes Including Tapered Sidewalls, and Fabrication Methods Therefor*, filed September 19, 2002, the disclosure of which is incorporated by reference herein as if set forth fully, may also be suitable for use in embodiments of the present invention.

The LEDs and/or lasers may be configured to operate such that light emission occurs through the substrate. In such embodiments, the substrate may be patterned so as to enhance light output of the devices as is described, for example, in the above-cited U.S. Patent Publication No. US 2002/0123164 A1.

Figure 1G is a cross-sectional view of other embodiments of the present invention. As shown in Figure 1G, a mounting substrate 170 is provided, such that the light emitting device 160 is between the mounting substrate 170 and the transparent inner core 150. As also shown in Figure 1G, in some embodiments, the mounting substrate 170 includes a cavity 172 therein and the light emitting device 160 is at least partially in the cavity 172.

Finally, Figure 1H illustrates yet other embodiments of the present invention. In these embodiments, the cavity 170 may be filled with an encapsulant 180, such as epoxy and/or other optical coupling media (e.g., silicon). The encapsulant 180 can enhance optical coupling from the light emitting device 160 to the transparent inner core 150. The design and fabrication of mounting substrates 170 that may be used in some embodiments of the present invention, are described in concurrently filed U.S. Patent Application Serial No. \_\_\_\_\_ to Negley, entitled *Solid Metal Block Mounting Substrates for Semiconductor Light Emitting Devices, and Oxidizing Methods for Fabricating Same* (Attorney Docket 5308-311), assigned to the assignee of the present application, the disclosure of which is hereby incorporated herein by reference in its entirety as if set forth fully herein.

It will be understood by those having skill in the art that, although the embodiments of Figures 1A-1H have been illustrated as separate embodiments, various elements of Figures 1A-1H may be used together in various combinations and subcombinations of elements. Thus, for example, combinations of inner and outer coatings 140 and 130, uniformly distributed phosphor 110 and nonuniformly distributed phosphor 120, light emitting devices 160, mounting substrates 170, cavities 172, inner cores 150 and encapsulant 180 may be used together. Accordingly, the present invention should not be limited to the separate embodiments that are shown in Figures 1A-1H.

Figure 2A is a cross-sectional view of light emitting devices according to other embodiments of the present invention. As shown in Figure 2A, these embodiments include an outer shell 200 which may be made of optically clear material that is loaded with phosphor and/or other chemicals. An inner core 250 may be made of optically clear material such as plastic or glass and may be placed on an encapsulating-containing cavity 272 in a mounting substrate 270. The outer shell 200 and the inner core 250 form a composite lens for a light emitting diode 260.

Figure 2B is a cross-sectional view of light emitting devices according to still other embodiments of the present invention. As shown in Figure 2B, these embodiments include an inner shell **202**, which may be made of optically clear material such as a polymer loaded with phosphor and/or other chemicals. An outer  
 5 shell **252** may be made of optically clear material such as plastic or glass. An encapsulating cavity **272** and a mounting substrate **270** are provided, as was the case in Figure 2A, to form a composite lens for light emitting diode **260**.

Figures 3A-3F are cross-sectional views of transmissive optical elements according to still other embodiments of the present invention that may be used to form  
 10 keypad keys which may be used, for example, in cell phones, automobile dashboards, portable computers and other conventional devices that include an illuminated keypad. Referring now to Figure 3A, a transmissive optical element includes a keypad key shell including a keypad key face **300** with phosphor **310** dispersed therein. In Figure 3A, the phosphor **310** is uniformly dispersed therein, whereas in  
 15 Figure 3B, the phosphor **320** is nonuniformly dispersed therein. Nonuniform dispersion may provide different light intensity, different colors and/or indicia as was described above.

In Figure 3C, the keypad key also includes a keypad key wall **330** that extends from the keypad key face **300**. In Figure 3C, the phosphor **310** is uniformly  
 20 distributed in the keypad key face **300** and in the keypad key wall **330**. In Figure 3D, the phosphor **320'** is uniformly distributed on the keypad key face **300**, but is not included in the keypad key wall **330**. In Figure 3E, the phosphor **320** is nonuniformly distributed in the keypad key face **300** and is not included in the keypad key wall **330**.

Figure 3F illustrates a keypad key including a keypad key face **300** and a  
 25 keypad key wall **330** mounted in a housing **370** and including a light emitting device **360**, such as a semiconductor light emitting device, between the housing and the key, to emit light **362** through the keypad key face **300** and/or wall **330**. It will be understood that light guides may be used to position the semiconductor light emitting device **360** remote from the key. It also will be understood that various elements  
 30 shown in Figures 3A-3F may be used in combination and/or subcombination, so that, for example, uniformly and/or nonuniformly distributed phosphor **310**, **320**, **320'** may be used in a key face and/or key wall **330**. Accordingly, the invention should not be limited to the various combinations of elements that are individually shown in Figures 3A-3F.

Figure 4 is a schematic block diagram of an apparatus for forming transmissive optical elements according to various embodiments of the present invention. In particular, Figure 4 illustrates an injection molding apparatus that may be used to form transmissive optical elements according to various embodiments of the present invention. As shown in Figure 4, an injection molding apparatus includes a hopper **410** or other storage device in which a transparent plastic and/or phosphor additive **450** are provided. The transparent plastic and/or phosphor additive may be provided in pellet, powder and/or solid form. Other additives, such as solvents, binders, etc. may be included, as is well known to those having skill in the art. An injector **420** may include a heater and a screw mechanism that is used to melt the transparent plastic and phosphor additive and/or maintain these materials in a melted state, to provide a molten liquid that comprises transparent plastic and the phosphor additive. The injector **420** injects the molten liquid into a mold **440** via nozzle **430**. The mold **440** includes an appropriate channel **450** therein, which can be used to define the shape of the optical element, such as a dome or keypad key. Injection molding of optical elements is well known to those having skill in the art and is described, for example, in U.S. Patents 4,826,424; 5,110,278; 5,882,553; 5,968,422; 6,156,242 and 6,383,417, and need not be described in further detail herein. It also will be understood that casting techniques also may be used, wherein molten liquid that comprises a transparent plastic and a phosphor additive is provided in a female mold which is then coupled to a male mold (or vice versa) to cast the optical element. Casting of optical elements is described, for example, in U.S. Patents 4,107,238; 4,042,552; 4,141,941; 4,562,018; 5,143,660; 5,374,668; 5,753,730 and 6,391,231, and need not be described in further detail herein.

Figure 5 is a flowchart of steps that may be used to manufacture transmissive optical elements according to various embodiments of the present invention. As shown in Figure 5, at Block **510**, a mold, such as mold **440** of Figure 4, is filled with molten liquid that comprises a transparent plastic and a phosphor additive. At Block **520**, the molten liquid is allowed to solidify to produce the optical element having phosphor dispersed therein.

Figure 6 is a flowchart of steps that may be performed to manufacture semiconductor light emitting devices according to embodiments of the present invention. As shown in Figure 6 at Block **610**, a shell such as a dome-shaped shell **100** of Figure 1A, that comprises a transparent plastic including a phosphor dispersed

therein, is molded using injection molding, casting and/or other conventional techniques. At Block 620, a core such as a core 150 of Figure 1E is formed. It will be understood that, in some embodiments, the core 150 is placed or formed inside the dome-shaped shell 100, whereas, in other embodiments, Block 620 precedes Block 610 by forming a transparent core 150 and filling a mold that includes a transparent core 150 with a molten liquid that comprises a transparent plastic and a phosphor additive, to form the dome-shaped shell 100 around the transparent core.

Still referring to Figure 6, a semiconductor light emitting device, such as device 160 of Figure 1G, is placed on a mounting substrate such as mounting substrate 170. At Block 640, an encapsulant, such as encapsulant 180 of Figure 1H, is applied to the mounting substrate 170, the light emitting device 160 and/or the core 150. Finally, at Block 650, the shell is mated to the mounting substrate using an epoxy, a snap-fit and/or other conventional mounting techniques.

It may be desirable for the inner core 150 to fill the entire lens, so as to reduce or minimize the amount of encapsulant 180 that may be used. As is well known to those having skill in the art, the encapsulant 180 may have a different thermal expansion coefficient than the mounting substrate 170 and/or the inner core 110. By reducing or minimizing the amount of encapsulant 180 that is used at Block 640, the effect of these thermal mismatches can be reduced or minimized.

It should also be noted that in some alternate implementations, the functions/acts noted in the blocks of Figures 5 and/or 6 may occur out of the order noted in the flowcharts. For example, two blocks shown in succession may in fact be executed substantially concurrently or the blocks may sometimes be executed in the reverse order, depending upon the functionality/acts involved.

Accordingly, some embodiments of the present invention can form a composite optical element such as a lens using molding or casting techniques. For example, keypads for a telephone may use a two-step injection molding process to form a two-color key, or to use a lower cost plastic to give mechanical stability while using only a thinner layer of more expensive material to enhance the appearance and reduce the cost. In some embodiments, injection molding can be used to place a phosphor layer dispersed in the molding material on the inner or outer surface and then completing the molding or casting process in the remaining volume, to form a desired optical element. These optical elements can, in some embodiments, convert a blue light emitting diode behind the key or dome, to white light.

Other embodiments of the present invention may use the phosphor to evenly disperse the light and/or to disperse the light in a desired pattern. For example, conventional light emitting devices may emit light in a "Batwing" radiation pattern, in which greater optical intensity is provided at off-axis angles, such as angles of about 40° off-axis, compared to on-axis (0°) or at the sides (for example, angles greater than about 40°). Other light emitting diodes may provide a "Lambertian" radiation pattern, in which the greatest intensity is concentrated in a central area to about 40° off-axis and then rapidly drops off at larger angles. Still other conventional devices may provide a side emitting radiation pattern, wherein the greatest light intensity is provided at large angles, such as 90° from the axis, and falls rapidly at smaller angles approaching the axis. In contrast, some embodiments of the present invention can reduce or eliminate angular-dependent radiation patterns of light output from a light emitting device, such as angular dependence of Color Correlated Temperature (CCT). Thus, light intensity and the x,y chromaticity values/coordinates from all surfaces of the lens can remain relatively constant in some embodiments. This may be advantageous when used for illumination applications, such as a room where a spotlight effect is not desirable.

Injection molding processes as described above, according to some embodiments of the invention, can allow formation of a single optical element with multiple features, such as lensing and white conversion. Additionally, by using a two-molding or casting technique, according to some embodiments, one can shape the phosphor layer to its desired configuration, to reduce or minimize the angular dependence of color temperature with viewing angle.

In the drawings and specification, there have been disclosed embodiments of the invention and, although specific terms are employed, they are used in a generic and descriptive sense only and not for purposes of limitation, the scope of the invention being set forth in the following claims.